

# Medical visualization with new generation spatial 3D displays

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## Abstract

*In this paper the capabilities of a modern spatial 3D display are exploited for medical visualization tasks. The system gives multiple viewers the illusion of seeing virtual objects floating at fixed physical locations. The usage of this kind of display in conjunction with 3D visualization techniques helps disambiguating complex images, so it is proven to be a real advantage for immediate understanding and visualization of medical data. We demonstrate this by reporting on some preliminary test cases of direct volume rendering techniques (Maximum Intensity Projection and X Ray simulation), as well as an example of a collaborative medical diagnostic application for analysis of Abdominal Aortic Aneurysms.*

Categories and Subject Descriptors (according to ACM CCS): B.4.2 [Input/Output and Data Communications]: Input/Output Devices Image Display

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## 1. Introduction

Medical 3D data acquisition devices are increasingly available and able to provide accurate spatial information on the human body. Even though nowadays hardware capabilities and rendering algorithms have improved to the point that volumetric 3D visualizations can be rapidly obtained from acquired data, 3D reconstructions are not routinely used in most hospitals. This is both because physicians are traditionally trained to gather information from 2D image slices, and because 3D volumetric images displayed on traditional devices are often of questionable value because of ambiguities in their interpretations [KST\*06].

Our research focuses on advancing medical visualization by combining 3D rendering techniques with novel spatial 3D displays able to provide all the depth cues exploited by the human visual system. In this work, we discuss preliminary results of our ongoing research, focusing on two particular examples. We first discuss how a spatial 3D display can aid in disambiguating complex images produced by depth oblivious volumetric rendering methods. We then illustrate how to implement an interactive application for such a display, describing a collaborative medical diagnostic testbed for the analysis of Abdominal Aortic Aneurysms.

## 2. Related work

**3D display technology** In recent years a number of 3D display designs for naked eye view have been proposed. These are broadly classified into these categories: autostereoscopic displays integrated with head/eye-tracking systems [WEH\*98, RS00, PPK00]; multi-view displays employing an optical mask or a lenticular lens array [DML\*00, vBC97, MP04]; volumetric displays projecting light beams onto a semi transparent or diffuse surface positioned or moved in space, which scatters/reflects incoming light [MMMMR00, FDHN01, RS00]; pure holographic displays using Acosta-optic materials [SHLS\*95], or optically addressed spatial light modulators [SCC\*00, CKLL05], or digital micro-mirror devices [HMG03]. Our spatial 3D display is based on projection technology and it is capable of displaying a continuous image to many viewers within a large workspace angle, due to the high number of view-dependent pixels that contribute to a single image [BFA\*05]. It provides all depth cues of a holographic display without requiring a technology for real-time diffraction pattern generation.

**Volume visualization** In the last decade, research in the field of computer graphics and visualization, along with the growth of graphics and processing hardware capabilities, resulted in a choice of techniques for visualizing volumetric

datasets in a meaningful and appealing way. Specifically, traditional volume rendering techniques can be subdivided into physically-based volume rendering and volume illustration techniques. In physically based volume rendering, the volume is considered as a distribution of light-emitting particles at a certain density, and images are obtained by integrating a volume rendering integral along rays cast from the eye to the scene to render. Maximum Intensity Projection and X-ray simulation are simplified version of this approach [ME04]. Substantial effort has been put into accelerating techniques in order to accomplish interactive or even real-time performance, taking advantage of CPU based acceleration techniques or hardware acceleration using texture mapping or special purpose hardware [XYZ05, RSEB\*00, KKH02]. In volume illustration techniques, a physics-based rendering process is integrated with nonphotorealistic rendering (NPR) techniques to enhance the expressiveness of the visualization. NPR draws inspiration from such fields as art and technical illustration to develop automatic methods to synthesize images with an illustrated look from geometric surface models [RE01, LMT\*03, BKR\*05]. These techniques effectively convey information to the viewer [SES05]. In this paper we discuss some preliminary results obtained by employing simple direct volume rendering techniques, like MIP and X-ray.

### 3. Spatial 3D display overview

Our spatial display is based on projection technology and uses a specially arranged array of micro-display projectors and a holographic screen [BFA\*05]. The projectors are used to generate an array of pixels at controlled intensity and color onto the holographic screen. Each point of the holographic screen then transmits different colored light beams in different directions in front of the screen. As usual with holograms, each point of the holographic screen emits light beams of different colors and intensity in the various directions, but in a controlled manner. The display is thus capable of reproducing an appropriate light field for a given displayed scene.

The light beams that compose the light field are generated by optical modules arranged in a specific geometry. Each module contains a micro-display and special aspheric optics. A high-pressure discharge lamp illuminates all the displays, leading to a brightness comparable to normal CRT displays. The display system concept makes it possible to produce high pixel-count 3D images by optimizing the optical arrangement to the capabilities of the technology and the components applied. The prototype's overall 7.4M pixels originate from the resolution of the 96 LCD micro-displays, each 320x240. The optical modules are densely arranged behind the holographic screen, and all of them project their specific image onto the holographic screen to build up the 3D image.

In the current prototype, 96 optical modules project 240

pixels horizontally and 320 vertically. Each pixel on the screen is illuminated by 60 different LCDs, and the optical modules can be seen under different angles by looking from the pixel's point of view. The imaging optics of the modules have a wide angle, which results in a 50 degrees field-of-view. Since 60 independent light beams originate from each pixel in this field of view, the angular resolution of the display is 0.8 degrees.

The holographic screen transforms the incident light beams into an asymmetrical pyramidal form. The horizontal light diffusion characteristic of the screen is the critical parameter influencing the angular resolution of the system, which is very precisely set in accordance with the system geometry. In that sense, it acts as a special asymmetrical diffuser. With proper software control, the light beams leaving the various pixels can be made to propagate in specific directions, as if they were emitted from physical objects at fixed spatial locations.

## 4. Direct Volume Rendering

In order to demonstrate the efficiency of the spatial 3D display, we selected as test cases two depth oblivious techniques commonly employed in medical visualization: Maximum Intensity Projection and X-Ray volume rendering. These techniques were originally developed for visualizing images on 2D displays, and have the drawback that 2D views are really ambiguous, since no depth cues are present in the intensity channel, the occlusion is not considered, and shading is not present. The question we addressed is whether a 3D display is able to recover lost 3D info, and in the next subsections we prove that this is possible. The techniques are implemented by employing texture-mapping and alpha blending hardware-accelerated primitives.

### 4.1. MIP Volume Rendering

Maximum Intensity Projection (MIP) is a simple variant of direct volume rendering, where, instead of composing optical properties, the maximum value encountered along a ray is used to determine the color of the corresponding pixel [ME05]. An important application area of such a rendering mode, are medical datasets obtained by MRI (magnetic resonance imaging) or CT (Computer Tomography) scanners. Such data sets usually exhibit a significant amount of noise that can make it hard to extract meaningful iso-surfaces, or define transfer functions that aid the interpretation. MIP is considered very useful for visualizing angiography data sets, since the data values of vascular structures are higher than the values of the surrounding tissues. The biggest drawback is that intensity channel completely un-masks depth information; so, in normal 2D displays users are not able to disambiguate features and recognize which objects are at the front and which are at the back.

As a test case for our preliminary tests, we chose a rota-

tional angiography scan of a head with aneurysm. By using MIP volume rendering technique, only the contrasted vessels are visible (figure 4.1). In a 2D view, the positions and the crossings of vascular structures are not detectable, or can be wrongly interpreted. This is because the technique does not provide any depth information in a single image and does not support occlusion. For instance, in figure 4.1 we can see two crossing blood vessels, with the one at the front having an intensity less than the one at the back. From this point of view, the back one is visible at the intersection and hides the front vessel because of its higher intensity. This provides a wrong impression.

Now, if we look at the same dataset on our spatial display, we are able to recover all depth cues and we are able to instantaneously recognize the vascular structure because of the combination of stereo and motion parallax that override the impression from the color channel. Figure 4.1 shows a set of pictures taken from different positions in the display workspace. It is obviously impossible to convey all the visual information provided by the display using videos or images. Images are thus here only for illustrative purposes.

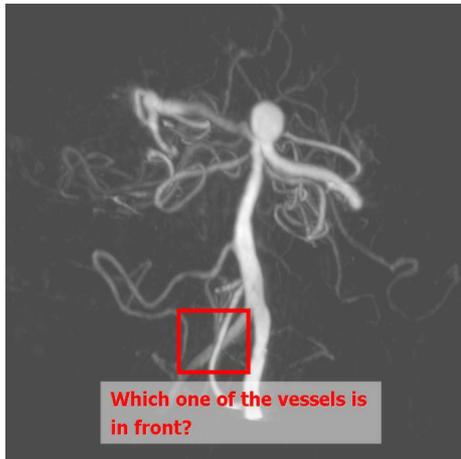


Figure 1: **Depth oblivious MIP angiography rendering.** MIP volume rendering of a rotational angiography scan of a head with aneurysm. The positions and the crossings of vascular structures are not detectable, or wrongly interpreted.

#### 4.2. X-ray Volume Rendering

In classical X-ray volume rendering, a viewing ray is cast through the center of each pixel and the line integral of the intensity is evaluated along the given ray [ME04]. In this case internal parts of the volume are visible, but depth information is not maintained. Hence, view disambiguation tasks are very hard to accomplish using 2D. As an example dataset for our preliminary tests, we considered a CT scan of abdomen and pelvis, containing also a stent in the abdominal aorta. In this case no contrast agent was used to enhance

blood vessels. A X-ray volume visualization is able to highlight bone and vascular structures, as shown in figure 4.2, but in 2D views it is not possible to distinguish between front and rear. Instead, observing the same dataset in the spatial 3D display, the user has the immediate understanding of spatial relationships, and he is able to easily distinguish between front and rear. Figure 4.2 shows a sequence of pictures taken from direct observation of the CT abdomen and pelvis dataset in the spatial 3D display. The sequence here is merely illustrative and it does not really provide the same “stimuli” provided by a direct experience with the spatial 3D display.



Figure 3: **Depth oblivious X-ray CT rendering.** X-ray volume rendering of a CT Scan of abdomen and pelvis. In 2D views, it is not possible to distinguish between front and rear.

#### 5. Collaborative medical diagnostic application

In order to exploit the features of the spatial 3D display system, we also developed an application for supporting diagnostic discussions and/or pre-operative planning of Abdominal Aortic Aneurysms.

The overall application is distributed using a client-server approach, with a Data Grid layer for archiving/serving the data, 2D clients for medical data reporting (textual/2D image browsing), and 3D clients for interacting with 3D reconstructions.

The 2D user interface for model measurement and reporting has been developed as a web application that can be run on a tablet PC or a palmtop computer. The application has been developed in PHP/Javascript and is based on the use of the Javascript XMLHttpRequest object to send and receive XML messages to/from the Holo application (which includes an HTTP server). HTML is dynamically updated according to the values parsed from the XML responses, and XML measurement reports are automatically generated.

The archive of models with related DICOM images and XML description files is stored in a distributed Data Grid archive based on San Diego Supercomputing Center’s Storage Request Broker (SRB). The web interface is based on



Figure 2: **MIP angiography rendering.** Direct capture from the spatial 3D display taken from different positions in order to disambiguate vascular structures.



Figure 4: **X-ray CT rendering.** Direct capture from the spatial 3D display taken from different positions in order to immediately understand spatial information.

server scripts that can be run on an Apache web server with `mod_php`. Scripts can perform queries to the SRB archive, transfer metafiles and data used to build the client interface (if not cached) and update the archive with the newly created reports. The only requirement for the user tablet/palmtop is the ability to run a lightweight javascript-enabled web browser, like Firefox. The interface display can be adapted to the screen resolution through the use of different stylesheets. Being based on the use of XML and stylesheets, the interface is also easily modified. It now implements user authentication, authorized 3D models search, analysis of metadata, images and other reports on the selected case and can drive the loading and measurement of the 3D model on the Holo display through the use of dedicated HTTP transactions.

The measurement interface allows the user to select a measurement procedure (typical of the model type), label and comment it and activate the corresponding thread in the holographic application, putting itself in waiting status. Once the measurement result is sent back (as XML), the interface becomes active again and the measurement results are added to the dynamic page representing the current report. When the report is complete it can be sent to the SRB

archive. The 3D application interacts with the SRB archive for data loading, and with the measurement interface for communicating anatomical measures.

The library and application have been developed on the Linux platform on top of the spatial 3D OpenGL wrapper, which has been concurrently refined to support most of the relevant OpenGL calls. The current prototype of the system is able to provide all the originally defined features (segmented surface based display, highlight, rotate, scale, clip, DICOM slicing). All the features are fully tested on regular 2D/3D displays. On a GeForce7950 system, the currently achieved frame-rate is about 27Hz, which proved sufficient to provide continuous motion in animation and 3D interaction tasks.

Since objects rendered on the spatial 3D display appear floating in fixed positions, it is possible to naturally manipulate them with a 3D user interface that supports direct interaction in the display space. In our application, operations are performed by selecting a current tool and then operating it with hand motions. Both mono-manual and bi-manual tools have been tested. In the case of mono-manual tools, each hand is attached to its own tool (e.g. the left one for model

motion, and the right one for model sectioning). In the case of bi-manual tools, the joint motion of both hands controls the tool behavior (e.g. rotation using the left hand to specify a center and the right one to specify axis and angle). A generic interface for controlling the 3D cursors has been developed. In the final version of the application, it is planned to employ a markerless camera-based hand tracking and posture recognition system, which is currently being developed. Gestures would be used to select tools, and hand motion to control cursors. Alternate cursor control interfaces have been developed, using both commercial 3D trackers (Logitech 3D mouse) and custom-made wireless solutions (camera based tracking of pointers, using wireless USB interface for buttons). Figure 5 shows some application snapshots, and illustrate the ability to perform collaborative tasks.

## 6. Conclusions and Future Work

In this paper we reported on some preliminary experiments in the usage of a spatial 3D display for medical visualization tasks. Specifically, we showed that 3D spatial display is very effective in resolving depth relationships of overlapping, if combined with direct order-independent volume rendering approaches (like X-ray and MIP).

Compared to existing and commonly employed technologies and visualization systems, a medical visualization system based upon 3D spatial displays provides lots of advantages. First of all, the display makes it possible to dynamically control a light field representation of 3D scenes. This means that users are able to reconstruct the spatial information using their own visual system in a natural way. Even when a single “static” 3D view is displayed, users can exploit stereo and motion parallax to understand complex shapes. Similar effects can be also obtained with traditional systems, but only by incorporating interactive manipulation in the rendering system. In this case, users will have to move the object or the viewpoint in such a way to provide the visual system with enough depth information. The task is not simple and immediate, and depth information is easily lost when the user stops the interaction with the object. Furthermore, this approach poses performance problems when exploring huge datasets with direct volume rendering techniques due to the need to continuous re-render the entire scene from novel viewpoints at high frame rates. On the other hand, a visualization system based on a spatial 3D display can employ very complex volume rendering schemes, based on non-photo-realistic rendering techniques, or accurate lighting and shading techniques. In the future, we plan to explore this field and perform some psychophysical testing in order to quantify the effectiveness of real spatial display with volume rendering for medical visualization tasks.

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## References

- [BFA\*05] BALOGH T., FORGÁCS T., AGOCS T., BALET O., BOUVIER E., BETTIO F., GOBBETTI E., ZANETTI G.: A scalable hardware and software system for the holographic display of interactive graphics applications. In *EUROGRAPHICS 2005 Short Papers Proceedings* (Conference Held in Dublin, Ireland, August 2005, 2005). 1, 2
- [BKR\*05] BURNS M., KLAWE J., RUSINKIEWICZ S., FINKELSTEIN A., DECARLO D.: Line drawings from volume data. *ACM Trans. Graph.* 24, 3 (2005), 512–518. 2
- [CKLL05] CHOI K., KIM J., LIM Y., LEE B.: Full parallax viewing-angle enhanced computer-generated holographic 3d display system using integral lens array. *Optic express* 13, 26 (December 2005), 10494–10502. 1
- [DML\*00] DODGSON N. A., MOORE J. R., LANG S. R., MARTIN G., CANEPA P.: Time-sequential multi-projector autostereoscopic 3D display. *J. Soc. for Information Display* 8, 2 (2000), 169–176. 1
- [FDHN01] FAVALORA G., DORVAL R., HALL D., NAPOLI J.: Volumetric three-dimensional display system with rasterization hardware. In *Stereoscopic Displays and Virtual Reality Systems VII* (2001), vol. 4297 of *SPIE Proceedings*, pp. 227–235. 1
- [HMG03] HUEBSCHMAN M., MUNJULURI B., GARNER H.: Dynamic holographic 3-d image projection. *Optics Express* 11 (2003), 437–445. 1
- [KKH02] KNISS J., KINDLMANN G., HANSEN C.: Multidimensional transfer functions for interactive volume rendering. *IEEE Transactions on Visualization and Computer Graphics* 8, 3 (2002), 270–285. 2
- [KST\*06] KERSTEN M. A., STEWART A. J., TROJE N., ELLIS R.: Enhancing depth perception in translucent volumes. *IEEE Transactions on Visualization and Computer Graphics Journal* 12, 6 (September-October 2006), 1117–1123. 1
- [LMT\*03] LU A., MORRIS C. J., TAYLOR J., EBERT D. S., HANSEN C., RHEINGANS P., HARTNER M.: Illustrative interactive stipple rendering. *IEEE Transactions on Visualization and Computer Graphics* 9, 2 (2003), 127–138. 2
- [ME04] MORA B., EBERT D. S.: Instant volumetric understanding with order-independent volume rendering. In *Eurographics 2004* (2004), vol. 23. 2, 3
- [ME05] MORA B., EBERT D. S.: Low-complexity maximum intensity projection. *ACM Transactions on Graphics*, 24, 4 (October 2005), 1392–1416. 2
- [MMMR00] MCKAY S., MAIR G., MASON S., REVIE K.: Membrane-mirrorbased autostereoscopic display for teleoperation and telepresence applications. In *Stereoscopic Displays and Virtual Reality Systems VII* (2000), vol. 3957 of *SPIE Proceedings*, pp. 198–207. 1
- [MP04] MATUSIK W., PFISTER H.: 3D TV: a scalable system for real-time acquisition, transmission, and autostereoscopic display of dynamic scenes. *ACM Transactions on Graphics* 23, 3 (Aug. 2004), 814–824. 1
- [PPK00] PERLIN K., PAXIA S., KOLLIN J. S.: An autostereoscopic display. In *Siggraph 2000, Computer Graphics Proceedings* (2000), Akeley K., (Ed.), Annual Conference Series, ACM



Figure 5: Snapshots from spatial 3D diagnostic system for Abdominal Aortic Aneurysm.

- Press / ACM SIGGRAPH / Addison Wesley Longman, pp. 319–326. [1](#)
- [RE01] RHEINGANS P., EBERT D.: Volume illustration: Non-photorealistic rendering of volume models. *IEEE Transactions on Visualization and Computer Graphics* 7, 3 (2001), 253–264. [2](#)
- [RS00] ROBERTS J. W., SLATTERY O.: Display characteristics and the impact on usability for stereo. In *Stereoscopic Displays and Virtual Reality Systems VII* (2000), vol. 3957 of *SPIE proceedings*, p. 128. [1](#)
- [RSEB\*00] REZK-SALAMA C., ENGEL K., BAUER M., GREINER G., ERTL T.: Interactive volume on standard pc graphics hardware using multi-textures and multi-stage rasterization. In *HWWS '00: Proceedings of the ACM SIGGRAPH/EUROGRAPHICS workshop on Graphics hardware* (New York, NY, USA, 2000), ACM Press, pp. 109–118. [2](#)
- [SCC\*00] STANLEY M., CONWAY P., COOMBER S., JONES J., SCAT-TERGOOD D., SLINGER C., BANNISTER B., BROWN C., CROSSLAND W., TRAVIS A.: A novel electro-optic modulator system for the production of dynamic images from giga-pixel computer generated holograms. In *Practical Holography XIV and Holographic Materials VI* (2000), vol. 3956 of *SPIE Proceedings*, pp. 13–22. [1](#)
- [SES05] SVAKHINE N., EBERT D. S., STREDNEY D.: Illustration motifs for effective medical volume illustration. *IEEE Comput. Graph. Appl.* 25, 3 (2005), 31–39. [2](#)
- [SHLS\*95] ST.-HILLAIRE P., LUCENTE M., SUTTER J., PAPPU R., SPARRELL C. G., BENTON S.: Scaling up the mit holographic video system. In *Proc. Fifth International Symposium on Display Holography* (1995), SPIE, pp. 374–380. [1](#)
- [vBC97] VAN BERKEL C., CLARKE J.: Characterisation and optimisation of 3d-lcd module design. In *Stereoscopic Displays and Applications XVII* (1997), vol. 3012 of *SPIE proceedings*, pp. 179–186. [1](#)
- [WEH\*98] WOODGATE G. J., EZRA D., HARROLD J., HOLLI-MAN N. S., JONES G. R., MOSELEY R. R.: Autostereoscopic 3d display systems with observer tracking. *Image Communica-*
- tion - Special Issue on 3D Video Technology (EURASIP - 1998)* (1998), 131. [1](#)
- [XYZ05] XIE K., YANG J., ZHU Y. M.: Real-time rendering of 3d medical data sets. *Future Gener. Comput. Syst.* 21, 4 (2005), 573–581. [2](#)